Electronic Journal of Education, Social Economics and Technology
Vol. 7, No. 1, (2026), e1390
ISSN 2723-6250 (online)
DOI: https://doi.org/10.33122/ejeset.v7i1.1390

SAINTIS
publishing

Research Article

Enhancing Cognitive Learning Outcomes through STEM-Based Instruction: Evidence from High School Reaction Rate Learning

Ucia Mahya Dewi* and Agus Muliaman

Faculty of Teacher Training and Education, Universitas Malikussaleh, Aceh Utara, Indonesia, 24351
*Corresponding Author: uciamahyadewi01@unimal.ac.id | Phone: +6282279799021

ABSTRACT

This study examined the effect of the STEM learning model on improving students' cognitive learning outcomes in reaction rate topics using a quantitative experimental approach with a non-equivalent control group design. Two pre-existing classes were assigned as the experimental group (STEM) and the control group (Direct Instruction), both of which were given pretest and posttest assessments. The sample consisted of 70 Grade 11 students selected through purposive sampling, with 35 students in each group. The instrument used was a cognitive learning outcomes test measuring content, context, and cognitive competencies. Data were analyzed using descriptive statistics, normality testing, and the Mann–Whitney U Test at a significance level of 0.05. The results showed that the STEM group achieved a higher mean N-gain score (0.63) compared to the control group (0.38), with a statistically significant difference ($p < 0.05$). These findings indicate that the STEM learning model has a positive and significant effect on improving students' cognitive learning outcomes in reaction rate topics.

Keywords: Experimental Research; STEM; Reaction Rate; Cognitive Outcome

1. INTRODUCTION

The advancement of science and technology in the 21st century requires graduates who not only master conceptual knowledge but also possess critical thinking, creativity, problem-solving skills, collaboration, and technological literacy. Numerous studies emphasize that science education must shift from teacher-centered instruction toward student-centered learning that integrates interdisciplinary knowledge and applies concepts in real-world contexts to prepare learners for the digital era and the Industrial Revolution 4.0 (Abdul-Rahaman & Thomas Nipielim Tindam, 2024; De Loof et al., 2022; Fadillah et al., 2024). The STEM (Science, Technology, Engineering, and Mathematics) approach aligns well with these competencies, as it integrates multiple disciplines in solving authentic problems, thereby fostering higher-order thinking skills and workforce readiness (Chen et al., 2026; Fadilla, 2023).

Chemistry is often perceived as a difficult subject by students due to its abstract concepts, symbolic representations, and the complex relationships between macroscopic, microscopic, and symbolic levels (Khatimah & Chisbiyah, 2024; Ritonga, 2023). Several studies indicate that reaction rate is among the most challenging topics, where students frequently struggle to understand factors influencing reaction rates, the meaning of reaction order, and the interpretation of graphs and rate equations, largely because instruction emphasizes memorization rather than conceptual understanding (Nurmiati et al., 2025). Classroom observations reveal low interest in learning chemistry, passive learning behavior, and limited student engagement, as students tend to feel bored, show little enthusiasm, and merely follow procedural steps in laboratory activities without understanding their significance (Lou & Jaeggi, 2020; Nurmiati et al., 2025) These conditions suggest that chemistry instruction, particularly on reaction rate topics, has not fully supported the development of higher-order cognitive skills as expected in the 2013 Curriculum and the Pancasila Student Profile.

Low achievement in chemistry is reflected in students' cognitive outcomes that often fail to meet the Minimum Mastery Criteria, with learning dominated by lower-order thinking skills such as remembering (C1) and understanding (C2), while higher-order skills like analyzing, evaluating, and creating (C4–C6) remain underdeveloped (Muliaman et al., 2018; Setiawan et al., 2025). Research in secondary school chemistry indicates that cognitive achievement is strongly influenced by the quality of instruction; when learning models fail to actively engage students, cognitive gains tend to stagnate (Honcharuk et al., 2024). In reaction rate topics, studies have shown that prior to intervention, students' average scores were below the mastery level and conceptual understanding was shallow, especially in connecting concepts with real-life phenomena. Although improvements through cooperative models and structured worksheets have been reported, these gains are often moderate and inconsistent at higher cognitive levels (Lou & Jaeggi, 2020; Nurmiati et al., 2025). This highlights the need for instructional innovation that not only improves test scores but also strengthens students' cognitive structures and scientific reasoning abilities.

One major factor contributing to low cognitive learning outcomes is the continued dominance of teacher-centered instruction. Lecture-based teaching and procedural exercises position students as passive recipients of information, limiting opportunities for constructing knowledge, questioning, and independent problem-solving. Meta-analyses in STEM education indicate that traditional instructional strategies tend to produce lower learning achievement and retention compared to approaches integrating inquiry, problem-solving, and technology use(Chen et al., 2026; Hiğde & Aktamış, 2022). In chemistry, textbook-driven instruction and "cookbook-style" laboratory work are insufficient for developing higher-level cognitive processes such as analysis, synthesis, and conceptual generalization. Moreover, the lack of real-life contextualization makes it difficult for students to perceive the relevance of chemistry topics, including reaction rate, thereby reducing motivation and participation (Khatimah & Chisbiyah, 2024; Muliaman, 2021).

Studies on Problem-Based Learning (PBL) and cooperative learning in reaction rate topics show that when students are engaged in analyzing real-world problems and collaborating in groups, significant improvements in learning mastery can occur, with increases reaching up to 70% in some schools. Other interventions, such as Teams Games Tournament, have also improved average student scores above the minimum criteria, although early stages often show unstable gains due to adaptation to new methods (Dila Padilah & Ai Mahmudatussa'adah, 2025). These findings reinforce that active and collaborative instructional designs can enhance learning outcomes; however, there remains a need for models that systematically integrate disciplines and technology while emphasizing authentic problem-solving in line with 21st-century demands.

The STEM approach emerges as a promising innovation to address the limitations of conventional instruction and enhance students' cognitive learning outcomes in science, including chemistry. A meta-analysis of over 100 K–12 studies reported that integrated STEM education produces moderate to large effects on knowledge acquisition, cognitive skills, and problem-solving abilities compared to traditional instruction. At the secondary level, another meta-analysis found that STEM approaches are significantly more effective than conventional teaching, with a high effect size ($d = 1.71$), indicating substantially better learning outcomes in STEM classrooms (Fadillah et al., 2024; Rahmiati et al., 2024). These findings are supported by studies demonstrating that STEM integration enhances academic achievement, conceptual understanding, and analytical thinking skills, which are essential competencies for the 21st century(Abdul-Rahaman & Thomas Nipielim Tindam, 2024; Ginting et al., 2020; Muhammad Azeem & Dr. Shafqat Rasool, 2025).

In chemistry education, several studies show that STEM-based models and media can improve cognitive learning outcomes and higher-order thinking skills. Research on redox reactions revealed that STEM-based instructional media led to significant differences in cognitive outcomes compared to conventional teaching, with students in STEM classes demonstrating higher achievement and better conceptual understanding. Other reviews confirm that STEM approaches consistently produce moderate improvements in learning outcomes, indicating their effectiveness in high school chemistry (Fadilla, 2023; Fadillah et al., 2024). Additionally, research on small-scale chemistry integrated with STEM in reaction rate topics found that experimental groups achieved significantly higher learning outcomes than control groups, along with improvements in critical thinking, problem-solving, creativity, communication, and collaboration (Utmeemang & Buaraphan, 2024). Similar results were found in studies involving STEM-integrated project-based learning (PjBL), which significantly enhanced students' cognitive achievement, creativity, and higher-order thinking skills compared to conventional methods (Muliaman et al., 2022; Purba et al., 2024).

More broadly, longitudinal studies on integrated STEM (iSTEM) curricula show positive impacts on cognitive performance, particularly in mathematical knowledge application and technological understanding, with more pronounced effects over extended intervention periods (De Loof et al., 2022). STEM integration has also been shown to improve computational thinking skills and non-cognitive factors such as motivation and attitudes toward science, which correlate with better cognitive achievement (Yang et al., 2025). Other studies at the junior high-level report that STEM activities enhance science process skills, motivation, career interest in STEM fields, creativity, collaboration, and problem-solving abilities. Thus, STEM not only improves cognitive outcomes but also fosters a rich learning environment that supports both cognitive and affective development. Considering the demands of the national curriculum, which emphasizes 21st-century competencies, and the existing challenges of low cognitive learning outcomes and conceptual difficulties in reaction rate topics, the implementation of STEM-based instruction in high school is highly relevant. Integrating science, technology, engineering, and mathematics in reaction rate learning enables students to connect theoretical concepts with real-life applications, such as in the food industry, pharmaceuticals, and environmental contexts, making learning more meaningful. Furthermore, STEM-based project and problem-solving tasks allow students to analyze experimental data, interpret reaction rate graphs, and design simple engineering solutions related to reaction control (Khatimah & Chisbiyah, 2024; Setiawan et al., 2025; Utmeemang & Buaraphan, 2024).

Based on this discussion, there is a clear gap between the demands of 21st-century competencies and the current classroom practices in chemistry, which are still dominated by conventional approaches and characterized by low cognitive learning outcomes, particularly in reaction rate topics. On the other hand, empirical evidence demonstrates that

STEM-based learning can significantly enhance cognitive outcomes, higher-order thinking skills, and student engagement in science and chemistry education (Aisyah et al., 2025; Johan & Rohaeti, 2024; Lamb et al., 2015). Therefore, it is necessary to conduct research that specifically examines the effectiveness of the STEM learning model in improving high school students' cognitive learning outcomes on reaction rate topics, in order to provide empirical support for developing more relevant and effective chemistry instruction aligned with 21st-century educational demands.

The research problem addressed in this study is: Can the STEM learning model improve students' cognitive learning outcomes in reaction rate topics? The objective of this study is to determine the effect of the STEM model on students' cognitive outcome in reaction rate topics. The research hypotheses are formulated as follows: **Ha**: there is a significant effect of the STEM model on students' cognitive outcome in reaction rate topics; $\mathbf{H_0}$: there is no significant effect of the STEM model on students' cognitive outcome in reaction rate topics.

2. RESEARCH METHOD

This study adopted a quantitative approach utilizing an experimental method. The research design employed was a quasi-experimental non-equivalent control group design (Sugiyono, 2013), in which two existing classes were assigned different instructional treatments and subsequently evaluated using a posttest. This design is frequently applied in educational settings where random assignment is not feasible, yet it still enables causal inference through appropriate statistical procedures.

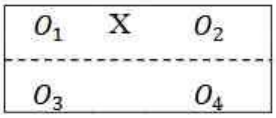

Figure 1. Non-Equivalent Control Group Design

Notation:

O_1 = Pretest scores of cognitive learning outcomes for students taught using the STEM model

O_2 = Posttest scores of cognitive learning outcomes for students taught using the STEM model

O_3 = Pretest scores of cognitive learning outcomes for students taught using Direct Instruction

O_4 = Posttest scores of cognitive learning outcomes for students taught using Direct Instruction

The population of this study consisted of all Grade 11 students who studied reaction rate at the selected school. The sample comprised two Grade 11 classes selected through purposive sampling (Sugiyono, 2013), based on specific criteria aligned with the research objectives, such as comparable prior knowledge, similar class schedules, and being taught by the same teacher. The research subjects included 35 students in the experimental class and 35 students in the control class. The independent variable in this study was the STEM instructional model, while the dependent variable was students' cognitive learning outcomes on reaction rate material. The experimental class received instruction through the STEM approach, whereas the control class was taught using Direct Instruction in the form of structured lectures. Both groups were exposed to the same subject matter, namely reaction rate.

The research instrument consisted of a cognitive learning outcomes test designed to measure various levels of students' cognitive abilities. The instrument was developed based on established assessment frameworks and was validated through expert judgment as well as empirical testing, including item difficulty analysis, discrimination index, item–total correlation, and reliability testing (Arikunto, 2021).Data were collected through the administration of a posttest on cognitive learning outcomes to both the experimental and control classes. Data analysis involved descriptive statistics, including mean scores, standard deviations, and score classification. Prior to hypothesis testing, the data were subjected to normality and homogeneity tests as prerequisites for parametric analysis. To examine the differences in cognitive learning outcomes between students taught using the STEM model and those taught using Direct Instruction, an independent samples t-test was conducted at a significance level of $\alpha = 0.05$.

3. RESULTS AND DISCUSSION

3.1 Results

Descriptive Statistics of Students' Cognitive Learning Outcomes

Data on students' cognitive learning outcomes were obtained from a posttest administered to both the experimental class (STEM) and the control class (Direct Instruction). The descriptive results are summarized in **Table 1**.

Table 1. Descriptive Statistics

	N	N-gain
Ngain Cognitive Learning Outcomes Score for the Experiment Class	35	0.63
Ngain Cognitive Learning Outcomes scores for the control class	35	0.38

The findings show that the mean score of students in the experimental class was higher than that of those in the control class. The mean difference between the two groups was 0.25 points, indicating a noticeable difference in cognitive learning outcomes. Furthermore, the score distribution in the experimental class generally fell within the moderate to high category, whereas the control class scores tended to range from low to moderate. These descriptive findings suggest that the implementation of the STEM model positively contributed to students' cognitive learning outcomes in the topic of reaction rate.

Assumption Testing

Before conducting hypothesis testing, the n-gain data were first analyzed to examine the assumptions required for statistical testing, including normality and homogeneity of variance.

Normality Test

The results of the normality test revealed that the cognitive learning outcomes data were not normally distributed, as the significance values (p) obtained were less than 0.05 ($p < 0.05$). Therefore, the assumption of normality was not fulfilled.

Table 2. Tests of Normality

Class		Shapiro-Wilk		
		Statistic	df	Sig.
Ngain Cognitive	Experiment	0,954	35	0,153
	Control	0,915	35	0,010
a. Lilliefors Significance Correction				

Based on the normality test, it was found that the data is not **normally** distributed because the sign value is < 0.05.

Hypothesis Testing

Since the normality assumption was violated, hypothesis testing was carried out using a non-parametric test, namely the Mann–Whitney U Test, to determine whether there was a difference in cognitive learning outcomes between students taught using the STEM model and those taught using Direct Instruction. The results of the analysis are presented in Table 3.

Table 3. Mann–Whitney U Test

Test Statistics^{a}	
	Ngain_Cognitif
Mann-Whitney U	0,000
Wilcoxon W	630,000
Z	-7,217
Asymp. Sig. (2-tailed)	0,000
a. Grouping Variable: Kelas	

The findings indicated that the significance value (Sig. 2-tailed) was less than 0.05 ($p < 0.05$). Consequently, the null hypothesis (H_0) was rejected, and the alternative hypothesis (H_1) was accepted. This indicates that the STEM model has a statistically significant effect on students' cognitive learning outcomes in the reaction rate topic.

3.2. Discussion

The quasi-experimental non-equivalent control group design with 35 students in each class shows that the STEM learning model produces higher cognitive learning gains than direct instruction, as indicated by N-gain 0.63 (experimental) versus 0.38 (control), both in the medium category but with a clear practical advantage of STEM. The moderate N-gain in the STEM class aligns with research where STEM-based inquiry or PBL produced medium–high gains in cognitive or related outcomes (Haryadi & Pujiastuti, 2023; Kartini et al., 2024; Sari & Putri, 2022; Sundari et al., 2021). For example, a STEM-based inquiry model reduced intrinsic cognitive load with N-gain 0.63 versus 0.18 in the control class, and STEM-based PBL increased students' cognitive scores significantly compared to conventional teaching (Nuryanto & Yuliardi, 2023). Studies on PjBL-STEM in chemistry report even higher gains (NG ≈ 0.81) and substantially higher posttest means than conventional classes (Setiawan et al., 2025), while STEM-based guided inquiry in chemistry labs yields large effect sizes on conceptual mastery (Sulastri et al., 2025). Your result (0.63 vs 0.38) is thus consistent with the general pattern that STEM outperforms traditional, teacher centered approaches in improving cognitive outcomes. In physics and general science, STEM approaches also commonly show higher N-gain than direct/lecture-based classes, for example N-gain 0.67 vs 0.46 in electric circuits learning (Haryadi & Pujiastuti, 2023), or better long-term retention in STEM workshops compared with expository teaching (Mateos-Núñez et al., 2020). These parallels reinforce that the significant difference found in your study (Ha accepted, H0 rejected) reflects a robust effect rather than random variation. STEM learning typically integrates problem solving, design, and technology in contexts meaningful to students. Such environments promote active engagement, collaboration, and higher-order thinking, which strengthen cognitive structures more effectively than direct instruction focused on explanation and practice alone (Adams, 2021; Aji et al., 2024; Aurelya & Carolina, 2024; Eroğlu & Bektaş, 2022; Utami et al., 2025). Studies of PBL-STEM and STEM projects highlight gains in critical thinking, creativity, and scientific reasoning that accompany improved test scores (Baulo & Puertos, 2025; Sulastri et al., 2025). These mechanisms likely operated in your STEM class, producing higher conceptual understanding of reaction rate than in the direct instruction class.

Direct instruction can raise scores, as seen in the medium N-gain (0.38), which is comparable to control classes in other quasi-experiments (Nuryanto & Yuliardi, 2023; Ummah & Nugroho, 2023). However, its limited emphasis on inquiry, model construction, and cross-disciplinary integration constrains the development of higher-order cognitive skills; this is reflected in systematically lower posttest or N-gain values relative to STEM approaches (Macea Anaya et al., 2024; Sernicula, 2025; Tiara & Sulistina, 2021). Using a non-equivalent control group design is appropriate and widely adopted in school-based STEM evaluations (Nuryanto & Yuliardi, 2023; Sernicula, 2025). Pretest–posttest with N-gain allows controlling for differing initial abilities and focuses on learning progress. Similar designs in STEM studies at secondary level consistently report significant advantages for the experimental group when implementation is coherent and teachers are adequately prepared(Lamb et al., 2015; Rahmiati et al., 2024). Your finding that both classes achieved medium N-gain but with a substantially higher value in the STEM group reflects both the baseline similarity and the added value of the intervention. First, the higher N-gain in the STEM class supports the conclusion that a STEM model is more effective than direct instruction in improving cognitive learning outcomes on reaction rate. This is congruent with evidence that STEM-based models enhance scientific competencies and academic achievement in chemistry and other sciences. Second, the medium category in both groups indicates that students still have room for deeper conceptual development; refining STEM tasks (more open-ended problems, richer engineering design, and explicit metacognition) could potentially move gains toward the high category, as reported in some PjBL-STEM chemistry studies. Third, the results strengthen the argument for shifting chemistry teaching—especially abstract topics like reaction rate—from direct instruction to integrated STEM designs to better align with 21st century competency demands (Adams, 2021; Baulo & Puertos, 2025). Overall, the significant difference and superior N-gain in the experimental class position your study within a growing body of research validating STEM models as an effective strategy to improve secondary students' cognitive learning outcomes.This quasi-experimental non-equivalent control group study with 35 students in each class demonstrated that a STEM learning model yielded higher cognitive gains on reaction rate than direct instruction, as shown by N-gain scores of 0.63 (experimental) versus 0.38 (control). Both values fall in the medium category, but the STEM class shows a clear practical advantage.The findings are consistent with numerous quasi-experimental studies reporting that STEM-based PBL, inquiry, or project learning produces significantly higher posttest scores, N-gain, and effect sizes in science and chemistry than conventional or direct teaching. Prior research attributes this superiority to active, contextual, and interdisciplinary learning processes that foster higher-order thinking, problem solving, and motivation. Given the similarity of the design and outcome pattern to previous work, the acceptance of Ha and rejection of H_0 in this study can be interpreted as robust evidence that STEM learning is more effective than direct instruction for improving senior high school students' cognitive achievement in reaction rate, while still leaving room for further optimization of STEM implementation.

4. CONCLUSION

Based on the statistical analysis of students' posttest scores on cognitive learning outcomes in reaction rate topics, it can be inferred that the average N-gain score of students who were instructed using the STEM learning model was higher than that of students taught through Direct Instruction. Furthermore, the application of the STEM model demonstrated a positive and statistically significant impact on students' cognitive learning outcomes compared to the use of Direct Instruction.

RECOMMENDATIONS

Based on the findings of this study, several recommendations can be proposed. The implementation of the STEM learning model should be integrated with authentic assessment approaches, such as project-based or problem-based tasks, to provide a more comprehensive evaluation of students' cognitive learning outcomes. Future research is suggested to involve different educational levels and a wider range of chemistry topics to examine the consistency of STEM effectiveness in improving cognitive achievement. Additionally, incorporating other variables, such as critical thinking skills, problem-solving abilities, and learning motivation, is recommended to capture the broader impact of the STEM approach. Further studies are also encouraged to employ more rigorous experimental designs, such as a pretest–posttest control group design, in order to obtain a more detailed analysis of students' cognitive learning gains. Moreover, qualitative or mixed-methods research is needed to gain deeper insights into students' learning processes, thinking patterns, and challenges encountered during the implementation of STEM-based instruction, particularly in reaction rate topics.

ACKNOWLEDGEMENTS

The authors would like to convey their sincere appreciation to the principal, chemistry teachers, and Grade 11 students of SMA Negeri 1 Muara Batu for their cooperation and support throughout the conduct of this study. They also extend their gratitude to colleagues and reviewers for their insightful suggestions and constructive feedback, which greatly enhanced the quality of this manuscript. This research would not have been successfully completed without the contributions and assistance of all parties involved.

REFERENCES

Abdul-Rahaman, A.-M., & Thomas Nipielim Tindam. (2024). Assessing the Effectiveness of Science, Technology, Engineering, and mathematics (STEM) Education on Students' Achievement in Secondary Schools. *EIKI Journal of Effective Teaching Methods*, *2*(2). https://doi.org/10.59652/jetm.v2i2.179

Adams, E. L. (2021). The effect of a middle grades STEM initiative on students' cognitive and non-cognitive outcomes. *Studies in Educational Evaluation*, *68*, 100983. https://doi.org/10.1016/j.stueduc.2021.100983

Aisyah, S. N., Sihaloho, M., Tangio, J. S., Lukum, A., Munandar, H., Thayban, T., & Kurniawati, E. (2025). The Effect of Using The PBL (Problem Based Learning) Learning Model Assisted by ChatGPT on Student Learning Outcomes in The Reaction Rate Material. *Jambura Journal of Educational Chemistry*, *7*(2), 94–102. https://doi.org/10.37905/jjec.v7i2.33888

Aji, L. S., Zamhari, M., Saputra, F. I., & Masrukhah, D. (2024). Comparing STEM and contextual approaches' impact on students' motivation and learning in acid-base materials. *Edu Sains Jurnal Pendidikan Sains & Matematika*, *12*(2), 193–204. https://doi.org/10.23971/eds.v12i2.8040

Arikunto, S. (2021). *Dasar-dasar evaluasi pendidikan edisi 3*. Bumi aksara.

Aurelya, V. A., & Carolina, H. S. (2024). The effect of PjBL-integrated STEM on students' cognitive learning abilities class x high school. *Edubiotik : Jurnal Pendidikan, Biologi Dan Terapan*, *9*(01), 54–60. https://doi.org/10.33503/ebio.v9i01.3979

Baulo, A., & Puertos, J. (2025). Comparative Effects of Direct Instruction and Educational Board Games on Chemistry Learning Performance Among High School Students. *Psychology and Education: A Multidisciplinary Journal*, *V49*(I9), 1145–1153. https://doi.org/10.70838/pemj.490905

Chen, B., Chen, J., Wang, M., Tsai, C.-C., & Kirschner, P. A. (2026). The Effects of Integrated STEM Education on K12 Students' Achievements: A Meta-Analysis. *Review of Educational Research*, *96*(2), 619–668. https://doi.org/10.3102/00346543251318297

De Loof, H., Boeve-de Pauw, J., & Van Petegem, P. (2022). Integrated STEM Education: The Effects of a Long-Term Intervention on Students' Cognitive Performance. *European Journal of STEM Education*, *7*(1), 13. https://doi.org/10.20897/ejsteme/12738

Dila Padilah, & Ai Mahmudatussa'adah. (2025). The Implementation of the Teams Games Tournament (TGT) Cooperative Learning Model to Improve Learning Outcomes on the Chemical Reaction Rate Topic in Grade XI. *Co-Catalyst: Journal of Science Education Research and Theories*, *3*(1), 11–18. https://doi.org/10.33830/cocatalyst.v3i1.13224

Eroğlu, S., & Bektaş, O. (2022). The effect of 5E-based STEM education on academic achievement, scientific creativity, and views on the nature of science. *Learning and Individual Differences*, *98*, 102181. https://doi.org/10.1016/j.lindif.2022.102181

Fadilla, A. N. (2023). Science, Technology, Engineering and Mathematics (Stem) Approaches to Improving Students' Learning Outcomes in the Subject of Redox Reactions. *Jurnal Pembelajaran Sains*, *6*(1), 41. https://doi.org/10.17977/um033v6i1p41-47

Fadillah, M. A., Hirahmah, A., Asrizal, & Usmeldi. (2024). The Effect of STEM-Based Interventions on Learning Outcomes in High School: A Meta-Analysis. *Journal of Innovative Physics Teaching*, *2*(2), 102–112. https://doi.org/10.24036/jipt/vol2-iss2/53

Ginting, F. W., Muliaman, A., Lukman, I. R., & Mellyzar, M. (2020). Analysis Of The Readiness Of Education Study Program Students To Become Pre-Service Teacher Based On Teacher Competency Standards. *Jurnal Pendidikan Fisika*, *9*(2), 120–127.

Haryadi, R., & Pujiastuti, H. (2023). Learning Electric Circuits Using the STEM Approach to Improve Scientific Thinking Skills and Practice. *International Journal of STEM Education for Sustainability*, *3*(2), 286–296. https://doi.org/10.53889/ijses.v3i2.223

Hiğde, E., & Aktamış, H. (2022). The effects of STEM activities on students' STEM career interests, motivation, science process skills, science achievement and views. *Thinking Skills and Creativity*, *43*, 101000. https://doi.org/10.1016/j.tsc.2022.101000

Honcharuk, V., Zadorozhna, O., & Parakhnenko, V. (2024). Formation of Cognitive Activity of Students in the Process of Studying Chemistry. *Pedagogy and Education Management Review*, (3(17)), 43–56. https://doi.org/10.36690/2733-2039-2024-3-43-56

Johan, E., & Rohaeti, E. (2024). Does the Integrated Discovery Learning STEM Model Improve Students' Problem-Solving Skills in Chemistry Learning? Meta-Analysis Study. *Jurnal Penelitian Pendidikan IPA*, *10*(3), 130–138. https://doi.org/10.29303/jppipa.v10i3.6879

Kartini, A., Husamah, H., Permana, F. H., & Mohd Shukri, A. A. Bin. (2024). PBL-based STEM: Its effect on the cognitive learning outcome of junior high school students. *Jurnal Biolokus*, *6*(2), 187. https://doi.org/10.30821/biolokus.v6i2.2673

Khatimah, M. H., & Chisbiyah, L. A. (2024). Fostering Engagement and Learning Outcomes: A Comparative Analysis of Ethnochemical and STEM-based Pedagogies for Chemistry Learning in Vocational High Schools. *Jurnal Pendidikan Sains*, *12*(1), 1–6. https://doi.org/10.17977/jps.v12i12024p001

Lamb, R., Akmal, T., & Petrie, K. (2015). Development of a cognition-priming model describing learning in a STEM classroom. *Journal of Research in Science Teaching*, *52*(3), 410–437. https://doi.org/10.1002/tea.21200

Lou, A. J., & Jaeggi, S. M. (2020). Reducing the prior-knowledge achievement gap by using technology-assisted guided learning in an undergraduate chemistry course. *Journal of Research in Science Teaching*, *57*(3), 368–392. https://doi.org/10.1002/tea.21596

Macea Anaya, M., Chimbo Jumbo, J., & Baena Navarro, R. (2024). Evaluation of a stem-based didactic model for the development of scientific competences in high school students: a quasi-experimental study. *Seminars in Medical Writing and Education*, *3*, 85. https://doi.org/10.56294/mw202485

Mateos-Núñez, M., Martínez-Borreguero, G., & Naranjo-Correa, F. L. (2020). Learning Science in Primary Education with STEM Workshops: Analysis of Teaching Effectiveness from a Cognitive and Emotional Perspective. *Sustainability*, *12*(8), 3095. https://doi.org/10.3390/su12083095

Muhammad Azeem, & Dr. Shafqat Rasool. (2025). The Effectiveness of STEM-Based Education in Promoting Positive Attitudes Towards Science Among Elementary School Students. *Social Sciences Spectrum*, *4*(1), 289–301. https://doi.org/10.71085/sss.04.01.219

Muliaman, A. (2021). Efektivitas Model Project Based Learning Berorientasi eXe Learning dan Motivasi terhadap Hasil Belajar pada Materi Laju Reaksi. *Jurnal Ilmu Pendidikan (JIP) STKIP Kusuma Negara, 13*(1), 51–57.

Muliaman, A., Fitriani, H., Usrati, K., & Mirnawati, M. (2022). Influence of Quantum Teaching Learning Model Assisted Digital Media (Edmodo) Toward Science Literature and Self-Efficiency of Highschool Students. *Jurnal Penelitian Pendidikan IPA*, *8*(5), 2525–2530. https://doi.org/10.29303/jppipa.v8i5.2328

Muliaman, A., on, R. S.-3rd A. I. S., & 2018, undefined. (2018). Relationship between Motivation and College Students Learning Outcomes on Chemical Kinetic Material at University. *Atlantis-Press.ComA Muliaman, RD Suyanti3rd Annual International Seminar on Transformative Education and, 2018•atlantis-Press.Com*. https://www.atlantis-press.com/proceedings/aisteel-18/55909051

Nurmiati, E., Wahyono, S. B., Rhomadan, M. R., Khairah, N., & Tafrienda, U. N. (2025). Development of Metacognition-Based LKPD to Improve Conceptual Understanding in Reaction Rate Material. *Jurnal Penelitian Pendidikan IPA*, *11*(4), 533–541. https://doi.org/10.29303/jppipa.v11i4.10464

Nuryanto, Y., & Yuliardi, R. (2023). Efektivitas Model Pembelajaran Problem Based Learning Berbasis STEM Terhadap Kemampuan Koneksi Matematis Siswa. *Indo-MathEdu Intellectuals Journal*, *4*(2), 179–192. https://doi.org/10.54373/imeij.v4i2.147

Purba, J., Panggabean, F. T. M., & Sutiani, A. (2024). Development of General Chemistry Teaching Materials Using the PjBL-STEM Model to Enhance Students' Creative Thinking Skills. *JTK (Jurnal Tadris Kimiya)*, *9*(2), 149–158. https://doi.org/10.15575/jtk.v9i2.39318

Rahmiati, R., Jalinus, N., Effendi, H., Fadillah, R., & Wulansari, R. E. (2024). Assessing the Impact of a STEM Learning Project Model on Artificial Intelligence Education in Higher Learning Institutions. *Data and Metadata*, *3*. https://doi.org/10.56294/dm2024.623

Ritonga, A. N. W. (2023). Problem Based Learning (PBL) Model to Improve Student Learning Outcomes In View From Cognitive Assessment On Material Reaction Rate. *Jurnal Pembelajaran Sains*, *6*(1), 52. https://doi.org/10.17977/um033v6i1p52-55

Sari, S. C., & Putri, R. E. (2022). The Effect of the PBL Learning Model Based on Science, Technology, Engineering, Mathematics (Stem) On the Cognitive Abilities of Junior High School Students 1 Basa Ampek Balai Tapan. *Universe*, *3*(1), 14–19. https://doi.org/10.24036/universe.v3i1.134

Sernicula, E. J. (2025). Effect of contextual and manipulative learning approaches on performance in chemistry of grade 12 STEM students. *Pantao (International Journal of the Humanities and Social Sciences)*, *4*(3). https://doi.org/10.69651/PIJHSS0403354

Setiawan, V. R., Situmorang, M., & Silaban, R. (2025). Project-based learning with STEM to promote higher order thinking skills as a strategy to improve high school chemistry learning outcomes. *Chemistry Teacher International*. https://doi.org/10.1515/cti-2025-0025

Sugiyono, D. (2013). *Metode penelitian pendidikan pendekatan kuantitatif, kualitatif dan R&D*. Alfabeta.

Sulastri, S., Mohamad Sattar Rasul, Juliana, Syahrial, & Ismi Zatya. (2025). STEM-Based Guided Inquiry in Colloid Practicums and Its Influence on Students' Concept Mastery. *Jurnal Pendidikan IPA Indonesia*, *14*(2). https://doi.org/10.15294/jpii.v14i2.23967

Sundari, R., Ahmed, O. S., Abdurrahman, A., & Herlina, K. (2021). Application Of Inquiry Based Learning Model Using Stem Approach to Reduce Students' Intrinsic Cognitive Load. *Insecta: Integrative Science Education and Teaching Activity Journal*, *2*(1), 87–94. https://doi.org/10.21154/insecta.v2i1.2482

Tiara, F., & Sulistina, O. (2021). Development of Pisa 2015 Based Chemical Literacy Assessment Instrument For High School Students. *J-PEK (Jurnal Pembelajaran Kimia)*, *6*(1), 26–40. https://doi.org/10.17977/um026v6i12021p026

Ummah, M. N., & Nugroho, D. E. (2023). The Influence of Steam Project-Based Chemistry Learning with the Assistance of Chemsketch on Learning Outcomes and Creative Thinking Ability on Macromolecular Materials. *Social, Humanities, and Educational Studies (SHES): Conference Series*, *6*(4). https://doi.org/10.20961/shes.v6i4.80876

Utami, V., Viyanti, V., & Permadi, D. (2025). Enhancing Students' Critical Thinking Skills: A STEM-Integrated Problem-Based Learning Model. *Jurnal Materi Dan Pembelajaran Fisika*, *15*(1), 17. https://doi.org/10.20961/jmpf.v15i1.102313

Utmeemang, R., & Buaraphan, K. (2024). Effects of small-scale chemistry STEM integrated with local contexts for enhancing grade 11 students' learning achievement and learning and innovation skills. *Ecletica Quimica*, *49*. https://doi.org/10.26850/1678-4618.eq.v49.2024.e1561

Yang, H., Hu, L., Wang, H., & Xin, Y. (2025). Impact of Integrating Computational Thinking in <scp>STEM</scp> Education on Students' Cognitive and Non-Cognitive Skills: A Meta-Analysis. *Journal of Computer Assisted Learning*, *41*(4). https://doi.org/10.1111/jcal.70079